type 2 diabetes, effect modification by sex was indicated, with stronger associations among women. There is some evidence from previous literature of a stronger association between noise and metabolic markers in women. For example, the cross-sectional HYENA (Hypertension and Exposure to Noise near Airports) study estimated associations of aircraft noise exposure with saliva cortisol in 439 men and women living near major airports in six European countries (Selander et al. 2009a). On average, women exposed to noise levels > 60 dB $L_{\mathrm{Aeq,24h}}$ had significantly higher morning saliva cortisol concentrations than women exposed to < 50 dB (β = 6.07 mmol/L; 95% CI: 2.32, 9.81), consistent with a noise-induced stress reaction. No such association was seen for men (β = –2.00 mmol/L; 95% CI: –5.61, 1.61). Furthermore, a recent population-based cohort study among 57,053 Danish residents reported an association between road traffic noise and diabetes (Sørensen et al. 2013). In this study, the incidence rate ratio for a 10-dB(A) L_{den} increase in average noise exposure during the 5 years preceding diagnosis was 1.11 (95% CI: 1.05, 1.18). Also, associations were stronger among females than among males. Yet, additional large-scale longitudinal studies are needed to clarify sex-specific associations between noise and metabolic outcomes.

Some of the individual characteristics we examined significantly modified associations with aircraft noise. High job strain, which was previously reported to be a possible effect modifier of the association between road traffic noise and myocardial infarction (Selander et al. 2013), was associated with greater increases in both BMI and waist circumference among participants exposed to aircraft noise levels ≥ 50 dB(A) compared with those exposed below this level. Thus, multiple stressors may add to the individual's stress load in a negative way. On the other hand, the association between noise and prediabetes was decreased among those with high physical activity compared with those with low activity, suggesting a buffering effect on the stress load. Furthermore, not changing home address during the study period was associated with stronger associations between aircraft noise and prediabetes as well as waist circumference, possibly a result of reduced exposure misclassification in this group. Unfortunately, small numbers of exposed cases of prediabetes and type 2 diabetes prohibited more detailed analyses of effect modification for these outcomes.

Sleep loss may have metabolic consequences by interfering with glucose regulation, control of appetite, and energy expenditure (Eriksson et al. 2008; Taheri et al. 2004; Van Cauter et al. 2008). However, in this study sleep disturbances were related neither to aircraft noise, possibly due to insulation of the most highly exposed residences, nor to any of the outcomes. Furthermore, our analyses of effect modification did not support the hypothesis of a moderating role of sleep disturbances on the association between aircraft noise and metabolic outcomes. However, an effect of sleep on metabolic outcomes should not be excluded because our assessment of sleep disturbances was based on self-report and rather crude.

Area-level socioeconomic factors may constitute strong sources of confounding in studies on environmental factors and health (Chaix et al. 2010). Because our study area included five different municipalities in Stockholm County—three in the northwest, close to Stockholm Arlanda airport, and an additional two in the southeast—we were concerned that regional differences in socioeconomic status might influence our results. In addition to individual-level factors, we therefore made adjustments for area-level mean income (yearly) and the proportion of unemployed residents. Neither mean income nor the proportion of unemployed was highly correlated to individual socioeconomic status, and adjustments for these factors tended to reduce the risk estimates for aircraft noise. This suggests that the association between aircraft noise and the outcomes may have been influenced by regional differences in socioeconomic status.

A limitation of our study is the narrow range of exposure and the small number of highly exposed cases. This was particularly evident for type 2 diabetes, where we had only 47 cases who had ever been exposed to aircraft noise and only 26 cases exposed at ≥ 50 dB(A). Thus, the associations between aircraft noise and prediabetes and type 2 diabetes in our study are uncertain.

Another limitation is the lack of objective data on exposure to noise from other sources, such as road traffic, railways, and occupation. Such sources may cause confounding, and though we adjusted for annoyance from these sources, some residual confounding may be present, particularly from road traffic and railway noise. Also, as described in a previous publication (Eriksson et al. 2010), the exposure to aircraft noise may have been underestimated for males because men were followed from an earlier time point, when the noise exposure was higher, than women were. Furthermore, women in Upplands Väsby may have been misclassified with regard to exposure because the opening of the third runway in 2003 led to increased aircraft traffic in this area. In fact, one-third of these women reported being disturbed by aircraft noise, although few of them were classified as exposed according to our exposure estimate. However, because we studied outcomes that develop during an extended period of time, changes in the noise exposure occurring late in the study period would not be expected to be of major importance.

Because only one OGTT was performed, there is some uncertainty in the classification of prediabetes and type 2 diabetes. The reproducibility of an OGTT may be reduced due to variation in the quality of the glucose measurements as well as intraindividual variations. In a systematic review of five studies, the reproducibility of a single test was 33–45% for IGT, 51–64% for IFG, and 73% for diabetes (Balion et al. 2007). Another reason for low reproducibility and misclassification is regression to the mean (Yudkin and Stratton 1996), indicating that individuals selected because they have a single high measurement will include a disproportionate number of individuals whose measurement by chance was higher than its true value. In our study, this may have led to misclassification of glucose tolerance.

Furthermore, our cohort oversampled persons with a family history of diabetes (approximately 50%, compared with 20–25% in the general population). Although we did not detect any statistically significant difference in the effects of noise exposure among those with family history of diabetes compared with those with no such history, the associations between aircraft noise and BMI as well as waist circumference appeared stronger among those without family history of diabetes. This could influence the possibilities to generalize our finding to the population as a whole.

Finally, the strengths of this study include its longitudinal design and the objective and independent estimates of the exposure as well as the outcomes. Information from questionnaires, clinical examinations, and high-quality registers (for area-level data) also enabled adjustment for potentially important individual and contextual confounders. Nevertheless, residual confounding may be present.

Conclusions

In conclusion, we estimated a statistically significant positive association between long-term aircraft noise exposure and change in waist circumference over time. These findings provide evidence of a link between aircraft noise and metabolic outcomes, especially central obesity. However, additional large-scale longitudinal studies are needed to confirm the association.

Correction

In Table 2 of the manuscript originally published online, the waist-difference values for women were incorrect. They have been corrected here.

References

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